SECTION 8. IMPACTS OF THE PREFERRED ALTERNATIVE

This section describes the potential ecological impacts of an artificial beach and dune construction alternative, as it has been the preferred alternative for similar Corps shoreline stabilization projects in North Carolina. If another alternative is selected as the Corps National Economic Development (NED) plan, substantial revisions will need to be made to this draft report to address the impacts of that alternative.

The Service has previously summarized the documented impacts of artificial beach and dune construction projects in USFWS (1999), USFWS (2000a), USFWS (2000b), USFWS (2001) and USFWS (2002a). These reports are incorporated by reference as their findings are applicable to this project as well, and this section supplements those reports with new scientific information not included in them. Recent studies and literature not previously reviewed expand the scientific knowledge of ecological impacts and recovery following dredge and fill projects. This information includes impacts during dredging at the dredge site and the physical environment that defines various microhabitats for invertebrates (the prey for birds and fish), fish, birds, and sea turtles.

Potential Impacts at the Offshore Dredge Site Habitats

The Minerals Management Service (MMS) is a bureau within the U.S. Department of the Interior that oversees the dredging of offshore materials from the seafloor, which are known as aggregate in the mining industry. The MMS issues appropriate permits or leases to dredge material from the seafloor more than three nautical miles from the shoreline. Recent proposals to dredge sands from waters under the purview of the MMS for beach nourishment projects has fostered several environmental studies by and for the MMS. One such report recently prepared for the MMS summarized the marine mining technologies and mitigation techniques currently available, including those for beach nourishment projects (C-CORE 1996). The findings of this report are summarized here, with the Executive Summary of the report reproduced in Appendix H; the entire report is available on-line at http://www.mms.gov/intermar/studies.htm.

While most species live within the upper 1 meter of the seabed (due to its aeration with oxygen), some larger species may live deeper in the seabed (1 to 2 m). "Large deep-living forms present a further concern [for ecological impacts] in that they may be long-living, slow-growing forms whose biomass may have taken 100 or more years to form. Once these forms ... are lost [through removal of the sediments] it may take decades to reestablish a potentially sustainable fishery. The loss may even be permanent" (C-CORE 1996, p. 13). The presence or absence of these species in the Bogue Banks project area are not known.

The recovery of the dredge site ecosystem depends on the sediment grain size, with fine-grained deposits (muds, silts, clays) achieving similar biodiversity levels within 1 year, medium-grained sands within 1 to 3 years, and coarse-grained deposits (> 2 mm) within 5 years or more. Recovery is defined by the authors as "a successional community of opportunistic species providing evidence of progression towards a community equivalent to that previously present, or at non-impacted reference sites" (C-CORE 1996, p. 22). The significance of the rate of recovery is unknown as other reports have documented recovery times of a few months to a few years for the offshore dredge sites (MMS 1999; Posey and Alphin 2000; Posey and Alphin 2002; Ray 2001; Van Dolah et al. 1992, 1994).

The C-CORE (1996) report makes several recommendations to avoid and minimize potential impacts to the marine ecosystem. For instance, in order to avoid the ecological impacts from the release of anoxic or toxic pore water from seabed sediments, patches of fine silts and clays that may occur within a dredge site should not be dredged. This potential impact is not likely to be significant for the Bogue Banks project because the high percentage of seawater within the dredge slurry (~85%) would dilute and mix any pore water with aerobic seawater. Also, the preferred sediment sources for dredge and fill projects are dominantly sand and avoid high concentrations of silts and clays.

The C-CORE (1996) review states that the level of suspended sediments generated by a cutterhead dredge rises exponentially with increasing cut thickness, rate of cutter swing, rate of cutter rotation and rate of production (Barnard 1978 as cited in C-CORE 1996, p. 137). Elevated turbidity levels at the seabed may occur up to 300 m from the cutterhead. This potential impact should not be significant for the Bogue Banks project if the dredge areas are located greater than 300 m from any hardbottom areas that would be adversely affected by increased turbidity levels.

Turbidity plumes generated by aggregate dredging may persist for long periods of time, potentially reducing light penetration and associated primary productivity; the planktonic food web may be affected as a result, although the turbidity plumes may have little or no impact on zooplankton (C-CORE 1996). The significance of this potential impact will depend on the project design since the impact should be temporary. The frequency of dredging may cause a persistent turbidity plume that reduces primary productivity for the life of the project if construction occurs on an annual basis similar to the Dare County (Bodie Island Portion) Beaches project (USACE 2000). The significance of this impact also depends on ambient turbidity levels within the project area, which may or may not be within the expected turbidity range of the dredging.

The dredging of seabed sediments temporarily may increase biological activity within the dredge site by attracting predators and scavengers to newly exposed, injured or killed organisms within the disturbed areas. The area may become "more attractive to fishing [as a result] but at unsustainable levels" (C-CORE 1996, p. 13). Some crustaceans (crabs, lobsters and others) that are omnivorous and live on the seabed may be able to survive smothering and burial resulting from turbidity plumes more easily than other less mobile epifauna. The authors theorize that this survival is enabled by the increase in prey for the crustaceans from other damaged species. The significance of this impact for the Bogue Banks project will depend upon the location, size and frequency of use of the targeted dredge site(s).

The sensitivity of the benthic community to a change in seabed sediment size varies with the species (C-CORE 1996). Some polychaete worms and crabs can be insensitive (or tolerant to changes in the seabed sediments) while "fishery species with dependent, specialist feeding and habitat requirements" are more sensitive to changes (C-CORE 1996, p. 23). The authors recommend identifying tolerable habitat changes prior to dredging and monitoring and mitigating appropriately. This potential impact can likely be avoided or minimized for the Bogue Banks Shore Protection Project by development of thresholds of change in coordination with resource agencies and other interested parties.

The biodiversity of the seabed community naturally fluctuates on an annual basis and many species occur in clusters rather than a uniform distribution across the seabed (C-CORE 1996). Many benthic-feeding fishery species, however, consistently are found in the same areas (commonly known as "fishing grounds") and their presence or absence is not directly related to the patchiness or annual fluctuation of their benthic prey. Survival of species with high territoriality (e.g., groundfish, marine mammals, birds) may be reduced if the dredging activities force the creatures away from their home sites. In addition, entire populations of species that make mass migrations along set routes during set seasons (e.g., marine mammals, sea turtles, marine birds, some fish and crustacea) may be exposed to dredging-induced impacts if the dredging occurs within their routes or migratory seasons. These potential impacts can be avoided through the appropriate site selection of the dredge site(s) for the Bogue Banks project.

Marine mammals that rely upon echolocation or sonar for feeding and travel are likely to be at risk from high noise levels from dredge operations, affecting foraging, breeding and their ability to protect themselves (C-CORE 1996). Equipment and vessel noise may be detected by marine mammals up to 190 kilometers (km) or more away, and behavioral changes may occur at 40 km or farther. The authors recommend making the dredges as quiet as possible and implementing a detailed recording of all on-board observations of marine mammal and other wildlife's reactions to the vessels and equipment. Another analysis summarized that most marine dredges may generate noise that exceeds the ambient noise level up to 25 km away from the vessel, but that the noise level varies with the individual dredge, with some dredges capable of emitting noise that is detectable at greater distances (Richardson et al. 1995). Several marine mammal species utilize the waters of the Bogue Banks Shore Protection project area, but the ambient noise levels in the project area without the project are not known. The presence of a deepwater port with tanker traffic may produce higher noise levels than marine dredges, but the latter noises tend to have longer durations than the commercial vessels (Richardson et al. 1995). Thus the significance of the potential noise impact from marine dredges utilized in the Bogue Banks Shore Protection Project is unknown and should be monitored in order to determine its significance.

In regards to ecological monitoring of dredge and fill projects, C-CORE (1996) concludes that the monitoring of impacts to the water column and its biological community is usually inadequate and does not sample on a frequent enough schedule to detect short-term impacts. The monitoring should be high intensity over a short period of time, with the goal of determining if water quality guidelines are being met. One example cited in the report was a beach nourishment project near Jacksonville, Florida, where the MMS required that nephelometer readings at the water surface, mid-depth and bottom not exceed 29 nephelometer turbidity units (NTU) at any time during the dredging operations. Preliminary data sampled along the beaches of Bogue Banks following the locally-funded beach fill project indicate that turbidity may exceed ambient levels for extended periods of time (Appendix G), generating a potentially long-term adverse impact.

Other studies have similar findings to those of the C-CORE (1996) report. The Dare County Beaches (Bodie Island Portion) project, for instance, may include dredging in the wintering grounds of striped bass (*Morone saxatilis*), a migratory fish species that may be significantly affected as a result (Laney et al. 2001). Downcurrent turbidity and sedimentation reduced the area available for recruitment of sessile epifauna by covering hardbottoms following dredging in the North Sea of the United Kingdom; the loss of adults stock subsequently reduced the possible juvenile recruitment in the area (Kenny and Rees (1994, 1993)).

Salomon et al. (1982) provides a survey of the high intensity, short-term nature advocated by C-CORE (1996). This project monitored the short-term recovery of dredge pits offshore Panama City, Florida, after dredging in the summer of 1976. The authors documented the rapid recovery of the benthic community of the dredge pit within 3 weeks post-dredging. Full recovery of the site was documented within one year. The researchers attribute the rapid recovery of the benthic community to the high wave energy environment (6 to 9 m water depth), the similarity of sediments exposed in the base of the pit to those present pre-dredging, and the quick burial of the silt and clay sediments that initially settled within the pit by sands moved into the pits by waves and currents. The dredge pits were excavated to 3 to 5 m deep and were filled in to 1 m below grade within the first year post-dredging. This study supports the findings of others that the sediments exposed by the dredging activities should closely match those exposed prior to the dredging in order to enable rapid recovery of a similar biological community.

More recently, Posey (2001) and Posey and Alphin (2002) monitored the recovery of the offshore dredge pit for a beach fill project at Kure Beach, North Carolina, for 2 years prior to 2 years after dredging (1995-99). The data from this study “suggest relatively quick recovery from borrow activities with interannual variability explaining more of the observed differences than sediment removal effects.” The timing of the dredging (in fall and winter) prior to peak infaunal recruitment periods, the opportunistic nature of several of the invertebrate species, and the limited size of the dredge site may be key factors responsible for limiting the long-term impacts from the sediment removal.

Ray (2001) found that the infaunal community at the offshore dredge site for a large-scale project in New Jersey was “numerically dominated by the archiannelid polychaete *Protodrilus* (LPIL), the amphipod *Pseudunciola obliquua*, and the tanaid *Tanaissus psammophilus*. Biomass was dominated by the sand dollar *Echinarachnius parma* as well as *S. solidissima*, *Ensis directus*, and the tellinid *T. agilis*, or a suite of polychaetes including *M. papillicornis*, paraonids, cirratulids, and nepthyids.” The dredging of beach fill material “resulted in decreased total abundance, biomass, taxa richness, and the average size of sand dollars. Species and biomass composition were altered in similar manners by each dredging operation: immediately after dredging the relative contribution of echinoderm biomass declined and the abundance of the spionid polychaete *Spiophanes bombyx* increased” (Ray 2001). The species abundance rapidly recovered following two dredging operations (1997 and 1999), “with no detectable difference between dredged and undisturbed areas by the following spring” (Ray 2001). The biomass and average size of the sand dollars, however, needed 2 to 2.5 years to fully recover.

Potential Impacts to Oceanfront Beach Habitats

Oceanfront beaches are highly dynamic habitats, continuously evolving in sediment volume, shape and substrate characteristics. Swales (2002), for example, found a statistically significant variation in the volume of sediment on a beach every 5.8 days. The author also found that at least 8 equally spaced transect profiles were necessary to reproduce the beach morphology accurately due to the spatial variability of beach habitats. This high dynamism lends further support to the recommendation for high-intensity, short-term monitoring to adequately document positive and negative impacts of a large scale dredge and fill project (C-CORE 1996).

The substrate in which sandy beach macrofauna burrow is influenced by both physical and biological processes. Meadows and Tait (1989) conducted laboratory experiments with a burrowing amphipod (*Corophium volutator*) and polychaete worm (*Nereis diversicolor*) to test alterations to the permeability and shear strength of estuarine muddy sands from bioturbation. Their study found that bioturbation by these burrowing organisms affects the permeability, water content and shear strength of the sediments. Water content decreased and shear strength increased with increasing densities of the two organisms, while permeability decreased with increasing numbers of the amphipod and increased with higher numbers of the polychaete (Meadows and Tait 1989). This indicates that the physical and biological features of a beach ecosystem are closely linked and share a complex interaction.

Several studies have shown that the fauna that live within a beach (the infauna) are indeed adapted to the physical parameters defining beach microhabitats. McArdle and McLachlan (1992) analyzed the physical habitat features important to sandy each macrofauna such as coquina clams, for instance. The authors "argue that swash climate on the beach face is the most important aspect of the environment experienced by animals inhabiting exposed sandy beaches" (McArdle and McLachlan 1992, p. 398). Several bivalves, crustaceans and gastropods are "swash-riders" that move up and down the intertidal portion of the beach with incoming swash and fluctuating tides. This study found that the wave height and beach slope are the two key factors responsible for the swash climate. The swash climate in turn affects the amount of water infiltrated into the beach and available to filter feeding organisms. The authors conclude that coquina clams are particularly sensitive to beach slope, and that "*Donax* sp. may select parts of a beach with flatter slopes *via* swash climate variables, *i.e.* an indirect response to slope *via* direct response to swash climate" (McArdle and McLachlan 1992, p. 405). Furthermore, they cite (McLachlan 1990) as support for the finding of macrofaunal sensitivity to beach slope and swash climate, stating that "there is a linear increase in intertidal macrobenthic species richness and a logarithmic increase in total abundance from reflective [steeper] to dissipative [flatter] beaches as well as a decrease in mean individual body size" (McArdle and McLachlan 1992, p. 405).

McLachlan et al. (1995) also found that bivalves are adapted to different beach types. The ability of the bivalves tested, including *Donax* sp., to burrow into sediments was not affected by beaches that were low wave energy and coarse sand, but were to high wave energy beaches with fine sand. Juveniles tend to burrow faster than adults. The authors conclude that "small species with high density and streamlined shape are best adapted to the dynamic swash conditions that characterise reflective beaches" (McLachlan et al. 1995, p. 147).

These studies suggest that to the extent that a beach fill project modifies the beach slope and/or wave energy climate, the project alters the specialized habitat of indicator species like coquina clams. If the beach is flat or dissipative pre-project, and if the addition of fill material or maintenance beach scraping steepens the beach, the species richness, abundance and size of individual organisms may be affected. These potential impacts may be significant in both a long-term and cumulative sense.

The fauna that live within a beach rely upon the continual input of sea water to provide food (since they tend to be filter feeders) and oxygen and to remove waste products. McLachlan et al. (1985) studied the infiltration of water (and thus the source of oxygen and food for filter feeding infauna) on beaches in western Australia with and without beach cusps and wrack material. The mean residence time of sea water filtered into a beach by wave swash was from 1 to 7 hours and percolated through 2 to 5 m of sediments. More water infiltrated into the beach on beach cusp horns than on embayments, with the net flow into the beach on the horns and out of the beach (as effluent) on the embayments. [Donoghue (1999) found that coquina clams preferred beach cusp horns to embayments.] Most of the sea water filtered into the beach through the upper part of the swash zone, where the water table was less than 20 cm from the beach surface. Chemical analysis of the interstitial water, or the water between the sand grains, yielded high concentrations of nutrients, and of phosphate in particular. The nutrient concentrations within the beach sands were greater than the water within the adjacent surf zone, and leachates from decomposing wrack material increased nutrient concentrations in the upper intertidal zone. Beaches composed of carbonate (shelly) sands may be comparably deficient in phosphate, however, due to its removal by the carbonate (McLachlan et al. 1985). Thus the removal of wrack material or addition of high shell contents as part of a beach fill and maintenance program may affect the nutrient cycling within a beach, and the meiofauna and filter feeding macrofauna accordingly. No nutrient data are known as of this time for the immediate project area.

The color of beach fill materials is another physical substrate parameter and has both ecological and aesthetic value. Ecologically, the color of the sediments may affect their temperature. Monitoring of the temperature of native and beach fill sediments placed on Bogue Banks during 2001-02 is currently underway by the NC Wildlife Resources Commission and preliminary results should be available soon. Previous reports by the Service summarized the affect of color and sediment temperature on incubating sea turtle nests (e.g., USFWS 1999, 2000a, and 2000b).

Browder (2002) describes the use of the Munsell Color Scale to determine the color compatibility of potential sand sources with the native sands of Pensacola Beach, Florida. The project sponsors designated the mineralogy (99% quartz), mean grain size (0.33 mm), sorting coefficient (0.47 phi) and color (Munsell Color Value of 9.25 or whiter and a chroma of 0.5 or less on the 2.5, 5, 7.5 or 10YR scale) for compatible sediments. The color and composition of the sediments were more important than the economic viability of obtaining the sediments to the local sponsors, and Escambia County passed an ordinance requiring any beach fill materials placed on Perdido Key or Santa Rosa Island have a Munsell color of 10YR 9.25/0.5. In order to meet this color criteria, exposure and oxidation testing was conducted on potential sediment sources to simulate weathering and bleaching of the fill material after placement. The solar exposure tests found that very little additional bleaching of the materials occurred after the first two weeks. Oxidation tests that washed the potential sediments with hydrogen peroxide produced similar results as the exposure tests, so the researchers concluded that the oxidation test adequately approximated the amount of initial lightening expected to occur following beach placement (Browder 2002). These methods provide a new way to ensure acceptable sediment compatibility in projects where color may be an issue, avoiding potential impacts to fish and wildlife resources.

Some beach fill construction and maintenance activities affect the dune system at the back of the beach as well as the wide, flat portion of the beach (the berm) and the intertidal areas. Shoreline stabilization projects often lead to the loss of natural features of beaches such as dunes, vegetation, and wracklines (Nordstrom 2000; Nordstrom 2001). Dunes built as part of a shoreline stabilization project often are designed as dikes, with "the location of the dune on the beach profile ... different from [its] location under natural conditions because [the] dune position is dictated by human preference rather than the interplay between vegetation growth, sediment supply and wave erosion" (Nordstrom 1994, p. 494). Extensive use of beach cleaning equipment has led to the removal of vegetation litter that naturally forms dunes. Dunes built by sand trapping with fences or vegetation plantings tend to be larger than would naturally form on those beaches (Nordstrom 1994).

Projects constructed in North Carolina typically involve the construction of a dune ridge as part of the design template. The beach fill used on the beach and to construct the dunes differs from natural windblown sand by containing coarser sediments than the wind would have normally transported to those areas. Nordstrom (1994) argues that nourished beaches are easily distinguishable from natural beaches due to their larger width and "the presence of coarse sediments on the surface of the backbeach. Accelerated deflation occurs [on nourished beaches], but dunes are rarely allowed to form in intensively developed areas [and] drift accumulations on the beach are removed to retain wide, flat recreation platforms" (p. 492). In addition, large buildings along the oceanfront shoreline may modify wind flow patterns, altering windblown sediment transport and accelerating the loss of sediment on the beach (Nordstrom 1994).

Within the project area, Conaway (2000) compared the aeolian transport, or windblown sands, at several dunes on Bogue Banks that had been scraped (bulldozed) and not scraped. Beach scraping artificially modifies the shape of the beach by pushing sediment from the intertidal zone to the base of the dune scarp, or to create an artificial dune or levee (and thereby modifying the physical habitat of intertidal and backbeach fauna and flora). The Conaway (2000) study found that beach scraping increased the amount of sands transported by the wind through increasing the amount of sediment available to be mobilized and by altering the shape of the dunes. The windblown sand transport rates were not significantly reduced by American beach grass (*Ammophila breviligulata*) plantings. "Despite substantial wind erosion, beach/dune profiles indicate that wave action was principally responsible for volume losses observed at scraped dunes" (Conaway 2000, p. ii). While the scraped dunes prevented erosion during minor storm events, they provided only minimal erosion control during a major storm event (Hurricane Floyd). The beach scraping also increased the slope of the beach, "suggesting that more stringent monitoring of scraping projects is necessary" (Conaway 2000, p. ii).

As a beach fill project erodes over time, the fill material also moves into adjacent aquatic habitats either downdrift or offshore. Reed and Wells (2000) mapped the distribution of dredged material sediment offshore Atlantic Beach and Fort Macon at the eastern end of the project area. Sedimentary characteristics were able to distinguish between native sediments, dredged material and relict sediments (or the underlying geology). The color, polish and size of shells were particularly useful indicators of the dispersal of dredged sediments off of the beach fill. Mapping of the distinct sediments suggests that little of the dredged material moved downdrift to Pine Knoll Shores and that cross-shore transport of the sediment (off the beach into deeper water) potentially is more effective at moving the dredged material.

Inlet areas often are targeted as a sediment source for beach fill projects in North Carolina (e.g., Shallotte Inlet, Masonboro Inlet, Mason Inlet, Rich Inlet, Bogue Inlet). Inlet habitats have been increasingly modified over time, via closures, dredging and jetty stabilization. "Dredging at ... inlets has changed the amount of sediment transferred across inlets and has influenced the location of accretion and erosion on adjacent shorelines by either changing the location of tidal channels or maintaining them in place, depending on human preference. ... Maintenance dredging ... keeps the [tidal] channel from fluctuating as widely as it would under natural conditions, and it reduces the periodicity of, or virtually eliminates, erosion/deposition cycles associated with breaching of the ebb tidal delta" (Nordstrom 1994, p. 489). These cycles of erosion and accretion govern the distribution of wet and dry inlet habitats for spawning fish, foraging and nesting birds, and migratory fish, sea turtles and marine mammals. The reduced variability in the distribution of these habitats has an unknown effect on these biota.

Potential Impacts to Sandy Beach Macrofauna

A study of the macrobenthos at Murrells Inlet, South Carolina, by Knott et al. (1983) is one of few studies surveying the invertebrate community at a tidal inlet. Of the 223 invertebrate species identified, polychaete worms were the dominant fauna both in numbers of species and individual populations. The intertidal zones were dominated by the polychaete *Scolelepsis squamata*, the amphipod *Neohaustorius schmitzi* and the coquina clam (*Donax variabilis*). The subtidal infauna were more diverse (208 species versus 88 in the intertidal areas) and were dominated by two polychaete species (*Spiophanes bombyx* and *Scolelepsis squamata*), two amphipods (*Protohaustorius deichmannae* and *Acanthohaustorius millsi*), and a bivalve (*Tellina* sp.). Species numbers and richness increased from the mean high water line seaward to 5 m water depth. Many of the species assemblages, of which the authors found 11, were spatially restricted to specific microhabitats. The authors conclude "that a distinct different in overall community structure exists between the intertidal and subtidal zones..., but it is important to note that many of the numerically dominant species are prevalent in both zones" (Knott et al. 1983, p. 586). They also determined that the invertebrate community structure is affected by the wave energy, with more species diversity, richness and evenness on semi-protected beaches (such as those sheltered by jetties) than at openly exposed beaches.

Several researchers at the University of North Carolina at Chapel Hill's Institute of Marine Sciences (IMS-UNC) have been conducting ecological studies in the project area in the past 5 to 10 years. Lindquist and Manning (2001) studied the impacts of beach bulldozing (scraping) and nourishment on surf zone fishes on Bogue Banks and North Topsail Beach. They found statistically significant declines in ghost crab populations 6 to 8 months following beach scraping, and the crab population did not fully recover prior to the next beach scraping event. "Hence, complete recovery of ghost crabs on beaches that undergo repeated scraping each year is unlikely" (Lindquist and Manning 2001, p. 1). There was no significant difference in the populations of coquina clams and mole crabs between scraped and non-scraped beaches, but the authors note that the high annual variability in populations may have masked any impacts caused by the scraping.

Most recently, these scientists have documented the recovery of infaunal beach populations following beach scraping and beach nourishment activities on Bogue Banks and Topsail Island (Lindquist and Manning 2001; Peterson et al. 2000; Peterson and Manning 2001). Both field surveys and laboratory experiments continue to be conducted by IMS-UNC during 2002 in the local beach fill project area and control beaches on Bogue Banks and Hammocks Beach (Appendix G).

To date the IMS-UNC research has documented that the faunal populations along the 6.75 miles of oceanfront beach that received beach fill between December 2001 and April 2002 are significantly depressed. Coquina clam (*Donax* sp.) and mole crab (*Emerita talpoida*) populations are 80% fewer in the beach fill as compared to control beaches, ghost crab (*Ocypode quadrata*) are 50% fewer, and shorebird abundances are 85% lower. More opportunistic species such as the polychaete worm, *Scolelpsis squamata*, have recovered, however. Turbidity levels within the surf zone are higher at the beach fill than at control sites, and frequently exceed the state salt water quality standards (C.H. Peterson, IMS-UNC unpubl. data, Appendix G).

The beach fill sediments used in this locally funded project were dredged from immediately offshore of Bogue Banks and contained between 30 and 40% carbonate material. In comparison, the native beach sediments of Bogue Banks contain less than 20% carbonate material (shells). Other beach fill projects that utilized beach fill sediments that more closely matched the native sediments showed ecological recovery of infaunal species within 8 months (e.g., Hackney et al. 1996, Ray and Clarke 1999, Saloman and Naughton 1984, Van Dolah et al. 1994).

A higher than background coarse-grained or carbonate fraction can inhibit the burrowing of beach infauna and the foraging of shorebirds (Alexander et al. 1993; Bowman and Dolan 1985; Lindquist and Manning 2001; Peterson et al. 2000). Laboratory experiments testing the sensitivity of burrowing coquina clams to various shell contents found that the clams have slower burrowing times with increasing sediment grain sizes (Lindquist and Manning 2001; IMS-UNC unpubl. data, Appendix G). Similar experiments with the burrowing ability of mole crabs found that burrowing times for large crabs are fastest within unsorted native beach sediments from Bogue Banks (mean grain size 0.177 mm or 2.5 phi) and significantly increase if the sediments are greater than or equal to 2 mm (-1.0 phi) or smaller than or equal to 0.0625 mm (4.0 phi; $P<0.05$). The burrowing times for small mole crabs does not significantly vary with grain sizes equal to or smaller than 1.00 mm (0.0 phi; P<0.05). When the sediment grain size is 4.0 mm (-2.0 phi) or greater, the time it takes a mole crab to burrow is approximately three times as long as when the sediments are unsorted natural Bogue Banks beach sands.

Alexander et al. (1993) also found that *Donax* spp. are substrate sensitive, with their burrowing rates varying with sediment grain size. The maximum burrowing efficiency of coquina clams is in fine sand (0.125 mm or 3.0 phi), with borrowing rates decreasing with both finer or coarser material (similar to the pattern documented for mole crabs by Lindquist and Manning 2001). The coquina clams appear more sensitive to finer grain sizes than to ones coarser than fine sand.

Experiments with shell contents ranging from the natural, unsorted content of Bogue Banks beaches to 80% shell material show that both small and large mole crabs are sensitive to increasing shell content (Appendix G). Significant increases in burrowing time of the crabs occur with 20% shell content as compared to the natural beach sediments of Bogue Banks (P<0.05). The same experiment for coquina clams indicate that their burrowing times significantly increase with 20 to 33% shell content as compared to natural concentrations on a non-nourished beach in the project area (P<0.05; L. Manning, IMS-UNC, unpubl. data in Appendix G). The shell content appears to camouflage invertebrate prey from foraging fish, reducing their ability to effectively forage even when the mole crabs and coquina clams have slower burrowing times (which could make them more vulnerable to predation; Dr. C.H. Peterson, pers. comm. September 4, 2002; Appendix G).

Monitoring of beach macroinvertebrates on North Topsail Beach following dredge disposal events in the springs of 1999 and 2000 found significant impacts to populations of ghost crabs, coquina clams (reduced by 50%), mole crabs (reduced by up to 100%), and several species of amphipods (reduced by half); the individual size distributions for mole crabs and coquina clams were smaller as compared to control beaches (Lindquist and Manning 2001, Peterson and Manning 2001). The dredged material studied in this project resulted in the sediments becoming finer than the pre-project beaches and increased turbidity in the surf zone during the disposal event (Peterson and Manning 2001). Turbidity experiments replicated in the laboratory documented a significant decline in the growth rates of coquina clams (which are filter feeders) by 25% under conditions similar to those measured in the field during the project (Peterson and Manning 2001).

Peterson and Manning (2001) concludes that the "impacts on the benthic macrofauna [at North Topsail Beach] were dramatic and longlasting" since the fauna did not recover in between disposal episodes (Peterson and Manning 2001). "[T]his project resulted in the reduction of habitat value of the intertidal beach for most surf fishes and shorebirds through reduced prey abundance and body size, a compound impact on production and trophic transfer" (Peterson and Manning 2001). Lindquist and Manning (2001) similarly conclude that "the repeated disturbance of beach disposal appears to prevent the full recovery of these populations and consequently results in their decreased productivity and decreased energy flow to vertebrate consumers" (p. 1).

Another recent scientific study conducted to monitor the impacts of dredge and fill projects on macrofauna was held in New Jersey. Ray (2001) found that the intertidal macrofauna species assemblage was similar to those found at other mid-Atlantic sandy beaches, with polychaete and oligochaete worms, haustoriid amphipods and mole crabs dominating the abundance. Many of the same species were found in the nearshore assemblage, but this assemblage was dominated by coquina clams and different species of polychaetes, amphipods and bivalves.

The sampling found that the abundance of the macrofauna peaked in the summer and was lowest in the middle of winter. The short-term impacts resulting from two beach fill episodes to the infauna included declines in taxa richness, biomass and abundance. At the mean low water line, the macrofauna recovered within 2 to 6.5 months of the beach fill placement. The researchers attribute differences in the recovery rates to the timing of when the beach fill operations were completed. The first beach fill episode (1997) resulted in no detectable change to subtidal infauna at 1 m water depth and the nearshore study area. The second beach fill episode (1999-2000) detected impacts persisting at 6 months post-construction. The reduced abundance and biomass measurements were within the variability of baseline conditions measured at non-nourished beaches, however (Ray 2001).

Rakocinski (2001) summarized a study on the impacts to macrofauna in various microhabitats on Perdido Key, Florida. The researchers posit that the more diverse species assemblages found offshore are less resilient to dredge and fill projects than those in the nearshore and beach habitats. An increase in the silt and clay loading occurred offshore following beach disposal and nearshore disposal of sediments (referred to as "profile nourishment" by the author), and this increase resulted in a change in benthic community structure for at least two years following construction. Total density and species richness decreased following the dredge and fill activities, the variability in these parameters increased, and the abundance of indicator species became more variable as well (Rakocinski et al. 1996).

Similar to the argument of Rakocinski (2001), Reilly et al. (1980) noted a difference in recovery of nourished beaches depending on the dominant community structure. Intertidal communities dominated by mole crabs and coquina clams, which have pelagic larval stages, may recover rapidly if the nourishment ends prior to the spring larval recruitment period. Beaches dominated by invertebrates who live their entire life histories on the beach (with no pelagic larval stage, e.g., *Haustorius* spp.) will have significantly longer recovery periods. The authors also state that beach nourishment activities typically increase the turbidity of adjacent waters by 3 to 4 times above the background level. Their conclusions recommend timing construction activities to avoid larval recruitment periods, use compatible materials to minimize turbidity, and to utilize "a few smaller sized non-continuous projects rather than one large one (to allow nearby 'seed' areas for organisms not recruited by pelagic larvae" (Reilly et al. 1980, p. 269).

Diaz (1980) conducted some of the earliest research on the mole crabs of Bogue Banks in 1972 and 1973. This research documented the life history of mole crabs in the project area, finding that the average lifespan of the mole crabs is about 2 years, there are two reproductive periods (spring and summer), recruitment of juveniles peaks during June-July and September-October, and that individuals may move downdrift along the beach anywhere from 10-15 m to 4-5 km in a single day (but no mass active migrations were measured, only passive transport on longshore currents). The author noted another study (Wolcott 1978) which found that although mole crabs constituted 41% of the diet of ghost crabs at Fort Macon, the mole crab population is not controlled by the ghost crabs. This life history information is useful in determining periods of high biological activity in the study area and potential recovery mechanisms (e.g., recolonization of a fill area by adult or larval recruitment).

Potential Impacts to Fish

The data available on potential impacts to fish from dredge and fill projects has been receiving increased attention. The high number of research organizations (federal, state and academic) in Carteret County has generated more data on fishery resources in the project area than any previous project in North Carolina.

Peters et al. (1995), for instance, studied the abundance of larval fish at Beaufort Inlet prior to an anticipated dredge disposal project at Atlantic Beach. At least 36 taxa (with 29 identifiable species) were collected in both larval and early juvenile states. The most abundant species were spot (*Leiostomus xanthurus*), Atlantic menhaden (*Brevoortia tyrannus*) and Atlantic croacker (*Micropogonias undulatus*). The abundance of larval and early juvenile fish varies with the seasons, with February, March and early April the months of peak abundance and therefore "probably not good times to conduct [dredge and fill] activities" (Peters et al. 1995, p. 4). The authors conclude that from the perspective of larval and early juvenile fish, dredging projects would have less impact if conducted in the late fall than during the late winter or early spring.

More recent research by biologists with the NOAA and the Corps has identified over 100 species of larval fish in or around Beaufort Inlet (L. Settle, NOAA, and H. Heine, USACE, pers. comm., October 18, 2002). The concentrations of larvae in the water column are such that the comparably low volume of water entrained by a 30 inch dredge in Beaufort Inlet is insignificant when compared to the tidal prism of the inlet. Thus the potential impacts to larval fish from dredge and fill projects appears to be insignificant.

In surveys of potential dredge sites offshore Bogue Banks, Peterson and Wells (2000) identified an average of 16,531 to 37,149 individuals per km^2 in the November 1999 survey, 1,087 to 9,882 per km^2 in February 2000 and 488 to 120,536 per km^2 in May 2000. Over half of the total catch in the November 1999 sampling were of spot (*Leiostomus xanthurus*), with pinfish (*Lagodon rhomboides*), pigfish (*Orthospristis chrysotera*) and croacker the next most common species in the offshore sampling area. The inshore sampling area was dominated by croaker (*Micropogonias undulatus*), silver perch (*Bairdiella chyrsoura*), silversides (*Menidia menidia*), pinfish and sea mullet *(Menticirrhus* sp.). Altogether 51 fishery species were found during the three survey periods, and fish gut content analyses indicate that the fish are using the invertebrates present in or on the seabed as a food source. The researchers concluded that "dredging could impact the demersal fishes and crustaceans by direct removal and mortality during dredging, by causing emigration to other areas, where crowding could reduce growth and production, and by creating some unknown period of time when benthic prey abundances had not yet recovered and so growth and production were reduced" (Peterson and Wells 2000, p. 9). In addition, if the dredging alters the sediments exposed on the seabed, the benthic invertebrate community may be changed and less food could be available to fishery resources than prior to the dredging.

In the same offshore and nearshore areas proposed for dredging, Coastal Science Associates (2002) conducted biological surveys of the macrobenthic fauna in June and November 2001. Species diversity ranged from 3.60 to 4.61 at the dredge sites and 3.88 to 4.72 at control sites. November densities were lower than those measured in June. Beach seines were used to sample surf zone fish along Bogue Banks, with 7 species caught in the June sampling period and 4 in the November sampling period. The more recent (November 2001) survey found highly variable species and numbers between stations but overall caught silverside, striped mullet (*Mugil cephalus*), summer flounder (*Paralichthys dentatus*) and Florida pompano (in order of decreasing abundance). Gut content analyses of 10% of the fish caught in beach seines indicate that coquina clams are the dominant food source, with mole crabs and silverside minnows also serving as prey.

Researchers at IMS-UNC conducted beach seine surveys during August 2002 along Bogue Banks, several months after Phase I of the locally-built beach fill project was completed (C.H. Peterson, IMS-UNC, unpubl. data, Appendix G). The seines were towed parallel to the beach, approximately 40 m from shore, simultaneously at beach fill and control sites. Three tows were conducted at each of 12 sites (6 control and 6 nourished). The average number of pompano and sea mullet caught at the control sites was slightly higher than the average number at nourished sites. The number of flounder and silverside did not differ between control and nourished locations. The average number of anchovy and menhaden captured at the nourished sites was much higher at nourished sites than control sites, however, differing by an order of magnitude. Additional fish surveys are scheduled for this fall (G.A. Johnson, IMS-UNC, pers. comm., September 11, 2002), which should provide additional data for determining if the beach fill project has negatively or positively impacted surf zone fish.

Since Florida pompano is regularly found along the beaches of Bogue Banks, scientists at IMS-UNC have held experiments to test the foraging ability of Florida pompano (*Trachinotus carolinus*) in various turbidity and shell environments that simulate field measurements taken during and after beach fill projects. One set of experiments replicated turbidity levels measured in the field following dredge disposal events on North Topsail Beach, and documented a 40.5% reduction in Florida pompano (a visual feeder) predation of coquina clams and 30% reduction on mole crabs (Lindquist and Manning 2001). Thus the turbidity created by a beach fill project can significantly reduce the foraging ability of at least one species of surf zone fish.

Experiments with coquina clams and pompano given various shell percentages (4:1, 2:1, and 1:1 shell:quartz sand ratios and quartz sand only with no shells) show that the foraging efficiency of the pompano also decrease with increasing shell content, with a statistically significant decline ($P<0.05$) between 0 and 50% or greater shell content (L. Manning, IMS-UNC, unpubl. data, Appendix G). The preliminary data from the IMS-UNC monitoring of the recent beach fill project on Bogue Banks, combined with this experimental data, suggest that recovery of indicator infauna species (and their predators such as Florida pompano) may be delayed by large increases in shell material within beach fill sediments. As a result, sediment compatibility with native beach sediments in the project area is a significant concern.

In addition to these studies within the project area, the recent beach fill project in New Jersey has been monitored for fishery impacts (Wilber 2001). The offshore fish species in this study consisted of winter flounder (*Pleuronectes americanus*), summer flounder (*Paralichthys dentatus*) and scup *(Stenotomus chrysops*). The presence of rock groins in the project area makes this study area different than Bogue Banks, but some of the surf zone fish species are the same (silversides). Bluefish (*Pomatomus saltatrix*) and northern kingfish (*Menticirrhus saxatilis*) were the other dominant fishes found in the New Jersey surf zone surveys. Prior to the beach fill project, the bluefish and silverside were captured more often near the groins, but after the project (when the groins were buried partially) these numbers decreased. "Kingfish abundances were significantly higher at beach nourishment sites than at reference stations, whereas, bluefish were more abundant in the reference area at the time of beach nourishment" (Wilber 2001). The distribution of silversides was the same at nourished and control sites, and the differences in bluefish and kingfish were not detectable 1 to 2 years following the beach fill placement. Gut content analyses of the fish "did not reveal any evidence that benthic prey availability was reduced by the beach nourishment project" (Wilber 2001).

Potential Impacts to Birds

North Carolina is along the Atlantic flyway for migratory birds, and the orientation and location of Bogue Banks in relation to Cape Lookout creates a situation where seabirds, shorebirds, colonial waterbirds and songbirds are all present in varying numbers throughout the year. Recent research has focused on the sensitivity of waterbirds to human disturbance, mammalian predators, and wetland foraging habitats.

Rodgers and Smith (1995) found that colonial waterbird nests are sensitive to human disturbance, and more sensitive to pedestrians approaching a nest than a motorboat. Experiments conducted by the researchers determined that wading bird colonies need a 100 m buffer and mixed tern and black skimmer colonies need a 180 m buffer. The terns and skimmers are more sensitive than other wading birds, leaving nests and taking flight with less provocation. Therefore if the Bogue Banks project proposes to work near a waterbird colony, these buffers serve as a guideline for setback distances for work areas to avoid significant impacts to the colony.

Erwin et al. (2001) surveyed the interaction between ground-nesting waterbirds and mammalian predators on the barrier islands of eastern Virginia. The range of the key mammalian carnivores (i.e., red fox (*Vulpes vulpes*) and raccoon (*Procyon lotor*)) has increased from 1975 to 1998, and the number of nesting waterbird colonies has decreased. The waterbird populations for common terns (*Sterna hirundo*), gull-billed terns (*S. nilotica*), royal terns (*S. maxima*) and black skimmers have "decreased dramatically," which the authors largely attribute to mammalian predation. Sandwich (*S. sandvicensis*) and least terns (*S. antillarum*) showed marginal population changes. The authors recommend the creation of dredged material islands as an alternative nesting and roosting habitat devoid of mammalian predators.

Moist soil substrates, such as bayside tidal flats or pools, are very important foraging habitat for nesting piping plovers (*Charadrius melodus*) and have been found to be preferential habitat for nest site selection (Fraser 2001). Unvegetated mud flats, sand flats and tidal pools are highly used by piping plovers during overwintering periods as well and may be essential for migratory juveniles. Prior to fledging, chicks that have access to these habitats may have higher survival rates compared to chicks without such foraging habitats. Twenty-two other shorebird and waterbird species have been documented to use the same moist substrate foraging habitats (Fraser 2001). Collazo (2001) also identified accessibility to wetland foraging habitat as a key variable in predicting shorebird abundance.

The Corps has sponsored monitoring of shorebirds and waterbirds in Brunswick County as part of two beach fill/disposal projects (the Ocean Isle hurricane protection and the Wilmington Harbor expansion projects). CZR (2002a) summarized the first year of monitoring at Ocean Isle following beach fill construction during the winter of 2000-2001. These surveys identified 29 species of waterbirds (peaking in abundance during the November fall migration period) and 17 species of shorebirds (also peaking during the fall migration) using the study area. The birds preferred the intertidal habitats in the survey area, spending three-quarters of the survey observations in those moist soil substrates. Nesting was attempted by Wilson's plover, American oystercatcher and willet during 2001 but none of the nests were successful; all of the nesting occurred near Shallotte Inlet, which also served as the dredge site for the beach fill. CZR (2002a) concluded that although there was a statistically significant difference in waterbird abundance between nourished and non-nourished areas, the absence of pre-project baseline data preclude an assessment of whether this was an effect of the beach fill or not. There were no significant differences in shorebird abundance or species richness detected. Piping plovers were observed in the study area during the spring and fall migration periods.

CZR (2002b) summarized similar avian monitoring at Holden Beach, Oak Island, Caswell Beach and Bald Head Island following the first year of dredge disposal from the Wilmington Harbor expansion project. The researchers concluded that the data were not sufficient yet to determine if the beach fill had impacted waterbirds or shorebirds. Both CZR (2002a) and CZR (2002b) found that the birds preferred inlet areas to oceanfront beach areas.

Potential Impacts to Sea Turtles

Two recent studies from Florida have added longer-term data on potential impacts to sea turtles from beach fill projects. Ernest (2001) monitored sea turtle nesting productivity on nourished and control beaches on Hutchinson Island, Florida, for three years. This study found that although the number of turtles emerging from the ocean to nest did not differ between nourished and non-nourished beaches, the number of nests as compared to false crawls decreased on the nourished beaches. The lower nesting success was documented on nourished beaches that were tilled and those that were not tilled, suggesting that compaction of the beach fill material was not the only determining factor in nest site selection. Those sea turtles that did nest used the entire beach width for nesting, often placing nests nearer the ocean on nourished beaches than on non-nourished beaches, increasing the risk for flooding and washouts as the beach fill equilibrated following initial placement   Ernest (2001) concluded that the "nourished beaches were generally more compact, wetter, coarser and warmer than those of control and pre-nourished beaches. Tilling significantly reduced compaction levels and effectively eliminated the impacts of high compaction (>500 psi) on the frequency of abandoned digs and the time required by turtles to excavate an egg chamber. The warmer sands of nourished treatments significantly reduced incubation periods and may have contributed to a higher incidence of late-stage embryonic mortality. However, despite changes in the incubation environment there were no significant differences in overall reproductive success."

Ernest (2001) recommends that impacts to sea turtles may be minimized if: (1) the beach fill is compatible with native sediments; (2) a more natural fill template is used; (3) adequate tilling is conducted; (4) nests laid on the seaward portion of the nourished beach are protected from washing out; (5) alternative methods of placing fill (e.g., stockpiling) be evaluated; and (6) monitoring programs distinguish impacts by utilizing baselines and controls.

Steinitz et al. (1998) conducted the first long-term (7 year) study of sea turtle nesting on nourished beaches in Florida. They found no significant difference in the successful hatching of eggs deposited on nourished beaches as opposed to adjacent non-nourished beaches. The number of nests deposited by nesting females was significantly lower on nourished beaches than the control beach, however. "Abandoned nesting attempts were positively correlated with the greater surface hardness of the renourished beach" for the first two years following nourishment, but nesting attempts were more successful with time as the surface hardness decreased. Over time as the nourished beach eroded to a narrower width, nesting densities again declined. "Thus, at Jupiter Island [Florida], less nesting occurred on renourished beaches because these sites cycled between relatively long and unattractive, and relatively short and attractive, 'states'" and "to the extent that other renourished beaches mimic these cycles, they also represent inferior nesting habitats" (Steinitz et al. 1998, p. 1000).

These studies indicate that there may be long-term impacts to nesting sea turtles resulting from beach fill projects. Recent experience with the local beach fill project, and the sensitivity of nesting sea turtles to the altered beach materials (i.e., more shells and a darker color), is being monitored. The first phase of this project used a hopper dredge to dredge seabed sediments for the beach fill. Unfortunately the hopper dredge sucked up 5 sea turtles, killing 4 of them, during periods when the water was warmer than 57 degrees Fahrenheit (in December 2001 and April 2002). Both Kemp's ridley (*Lepidochelys kempii*) and loggerhead (*Caretta caretta*) sea turtles were killed.

In summary, dredge and fill projects may cause significant ecological impacts at the dredge sites and to the variety of microhabitats found on the beach in the placement area. The impacts may last for a few months to several years depending on the timing of the construction, how the dredging and fill placement are conducted, and the compatibility of the fill material with the natural beach sediments and newly exposed sediments in the dredged pits. Some of the ecological impacts may be avoided and others may be minimized with existing technologies and practices.

SECTION 9. COMPARISON OF IMPACTS

The Service has previously summarized the comparative impacts of shoreline stabilization alternatives in USFWS (1999), USFWS (2000a), USFWS (2000b), USFWS (2001) and USFWS (2002a). These reports are incorporated here by reference. If hard stabilization alternatives (jetties, groins, seawalls, revetments, breakwaters, etc.) are developed, this section will require supplemental material.

The potential impacts of dredge and fill projects vary with several factors. These factors include the timing of the dredge and fill activities, the construction methodology, design template, sediment compatibility, and best management practices employed. The ecological impacts of these projects can be avoided and minimized with existing technologies and practices. This section summarizes project features that would avoid and minimize potential adverse impacts in the Bogue Banks project area.

First, the timing of project construction and renourishment (or maintenance) episodes is crucial to avoiding impacts to some species and minimizing impacts to others. If hopper dredges are to be used, dredging should be limited to periods when the waters are less than 57 degrees Fahrenheit to avoid sea turtles in the dredging areas. This period is generally late December through early April in the Bogue Banks area. If inlet areas are targeted as a sediment source or are immediately adjacent to beach fill areas, periods of peak larval and early juvenile fish presence should be avoided by dredging in the late fall rather than late winter and early spring. Beach fill placement should occur during periods of lowest invertebrate abundances on the beach, or between December and March for Bogue Banks. Migratory bird use peaks in early spring, with the nesting season for several species starting in March. Sea turtles nest in the project area from May 1 through November 15. The West Indian manatee (*Trichechus manatus*) may be present in project waters from June through the end of October. Local harvest of surf zone fisheries is conducted on the beach during the late fall. Fishing tournaments occur in the nearshore and offshore areas between June and November.

Reconciling these periods of biological productivity, impacts would be avoided and minimized the greatest if sediments sources were not located in inlets, beach fill does not occur adjacent to an inlet where end losses may be higher (e.g., the Bogue Banks Beach Restoration Project avoided the ~1 mile of beach closest to Bogue Inlet; CSE 2001), and construction is limited to the period between December and March 1. The actual start date may be determined by real-time monitoring of water temperatures and demersal fish and shrimp abundances in the targeted dredging area. The actual zone of influence of Bogue and Beaufort Inlets on adjacent shorelines should be assessed by the North Carolina Coastal Resources Commission's Science Panel on Coastal Hazards, which is formulating a methodology and specific data on other tidal inlets in the state.

The timing of maintenance episodes is one of the most critical factors determining the longevity of ecological impacts. Studies conducted at North Topsail Beach and Bogue Banks indicate that a one year interval between disposal or beach scraping episodes does not allow the sandy beach ecosystem to fully recover (Lindquist and Manning 2001, Peterson and Manning 2001, Peterson et al. 2000). Another study has found that a three year interval is not sufficient for full recovery at Pea Island (Donoghue 1999). More frequent fill activities increase the interannual variability of sea turtle habitat available for nesting (Steinitz et al. 1998), which typically fluctuates on a natural 3 year cycle. Therefore a maintenance (or renourishment) interval longer than 3 years would allow the greatest level of recovery of the ecosystem between episodes, avoiding a long-term or permanent loss of biological productivity in the fill area.

Secondly, the construction methodology influences the level of ecological impacts. Hopper dredges were already discussed for their known impact on entraining and killing sea turtles in the project area. While cutterhead dredges do not have the same impact on sea turtles, they do tend to dredge deeper cuts at the dredge site than hopper or dustpan dredges. In general, shallower cuts allow for faster recovery of the benthos than deeper cuts that may become stagnant and inhospitable to the pre-project benthic community (C-CORE 1996, MMS 2001).

Regardless of the dredge type, the methods used in excavating the sediments influence the recovery of the benthic ecosystem. Muddy and silty areas should be avoided to minimize turbidity caused by the dredging and any anoxic pore waters within the seabed. The area dredged for each fill episode should not be re-used until the seabed has fully recovered its community structure; in other words, the initial construction should dredge one area of the dredge site and the first maintenance episode should dredge a different area, etc. Side slopes in the dredge pits should be as gentle as possible, not leaving steep sidewalls that may slump and bury benthic infauna at a later date. The excavation cuts should not expose dissimilar sediments than what was present prior to dredging in order to facilitate recovery of the same community structure post-dredging (e.g., Peterson and Wells 2000, C-CORE 1996, MMS 2001). Leaving isolated pockets or "islands" of undisturbed seabed may also encourage quicker recovery of the benthic community after dredging (Hobbs 2002). Finally, barge overflows should be avoided so turbidity plumes and density currents are not generated. If economic loading is a preferred construction method, then on-board processing and dewatering techniques with directed subsurface discharge should be evaluated (see C-CORE 1996).

The design template also affects the magnitude and duration of ecological impacts. Longer projects tend to have more ecological impacts than shorter ones. Invertebrate species without pelagic larval stages depend upon gradual recolonization of the beach fill from the edges in. Shorter projects should recover more quickly than longer projects. The 24 mile long project area on Bogue Banks creates a situation where long sections of beach fill are likely to be designed. Dividing the beach fill into 3 or 4 sections, and constructing those sections in a non-contiguous fashion, should facilitate infaunal recovery of each individual section. If the maintenance or renourishment interval is once every 8 years, for instance, the project area could be divided into four sections of 5.25 miles each (avoiding up to 1.5 miles adjacent to each inlet). The four sections could be constructed on an alternating schedule of one every 2 years, with no two consecutive construction episodes contiguous to each other. The locally funded beach fill project is being constructed in three sections on a 10 year maintenance interval, but the three sections are being constructed in a contiguous sequence over an initial 3 year period.

The inclusion of a dune ridge or levee within the design template also poses potential ecological impacts. Bogue Banks has a high interior elevation with several relict dune ridges. The back portion of the oceanfront beach is typically backed by a steep dune scarp with very few breaches. The dune scarp has frequently been fronted by piles of sand pushed by bulldozers or trapped by sand fencing and planted vegetation. These existing activities impact the vegetation and the ghost crab population (Nordstrom 2001, Nordstrom 1994, Peterson et al. 2000), and incorporation of similar activities on a larger scale by including a dune ridge in the design template may increase the scale and duration of these impacts. Instead, ecological impacts may be minimized by utilizing the existing dune face into the design template. Sand fencing and planting diverse vegetation species in a more natural, random design (not rows) would have less ecological impact by allowing natural processes to form a foredune seaward of the dune scarp. The plantings could include seabeach amaranth, sea oats, bitter panicum and other species propagated from local stock in the Brunswick County facilities currently growing plants for beach use. Spacing the plants in an irregular pattern may provide nesting and shelter habitat for some shorebirds as well. Thus by capitalizing on natural processes, a potentially adverse design feature could become an environmental enhancement feature.

The fourth project feature that dictates the magnitude and duration of ecological impacts is sediment compatibility. When fill sediments closely match the native beach sediments in color, size and content (shell versus quartz), the beach ecosystem typically recovers in less than 8 months. If the material differs from the native sands, though, full recovery may not be detected prior to the next fill episode and the impacts may become permanent. Natural beaches in North Carolina have on average less than 4% silt and clay content, for instance. Fill material that includes higher silt and clay content has significant ecological impacts on sandy beach infauna and foraging fish (e.g., Lindquist and Manning 2001, Peterson et al. 2000, Peterson and Manning 2001). The locally funded beach fill project introduced excessive amounts of shell material to the beaches. Key indicator invertebrate species and foraging fish are sensitive to increased shell content (Lindquist and Manning 2001; L. Manning, IMS-UNC, unpubl. data, Appendix G) and recovery of these beaches is likely to take longer than the norm.

If the proposed federal project uses sediment that more closely matches the native sands of Bogue Banks than the locally funded project, the recovery of the beach ecosystem should be more rapid than that of the local project. Preliminary investigations of potential sediment sources indicates that such sediments are likely to be found in the inlets and the nearshore and offshore disposal areas. Bogue Inlet and Bogue Sound are high value resource areas and should be avoided as sediment sources for that reason. Archaeological resources in Beaufort Inlet indicate it should be avoided as a sediment source as well. The nearshore and offshore marine areas are also of high resource value, but they contain areas previously disturbed (the nearshore and offshore disposal areas). Targeting the nearshore and offshore disposal sites as a sediment source(s) would limit any disturbance to areas already disturbed by dredging activities. The deposition of material at these sites from dredging of the Morehead City navigational channel system may have already sorted undesirable material (silts and clays) from the dredged material. Thus these two areas may contain ecologically compatible beach fill material, and dredging of such material would avoid additional seabed disturbances to an area that has high resource value.

Targeting the nearshore and offshore dredged material disposal sites as a sediment source would also allow for best management practices to be incorporated into the project, limiting overall impacts to the Bogue Banks ecosystem. Maintenance dredging of the navigational channels in Beaufort and Bogue Inlets, the AIWW and the Morehead City port will continue without the project. As the dredging continues, the nearshore and offshore disposal sites will approach capacity and new sites will be needed. If the beach fill project recycles material from the dredged material sites, however, the capacity of the dredged material disposal sites will be increased. New offshore dredged material sites may be avoided, minimizing long-term and cumulative impacts to the high value seabeds of the project area. Recycling of this material to the beaches of Bogue Banks reintroduces it into the littoral system (defined in this report as the beach, surf zone and inlets) and offsets any erosional losses or shoreline fluctuations resulting from inlet dredging.

Another best management practice expands this regional sediment management approach to include the beach disposal operations at Atlantic Beach and the potential Section 933 project on Pine Knoll Shores and Indian Beach. A new federal beach fill project on Bogue Banks should incorporate these dredge disposal activities into this project, modifying the design template of the dredge disposal to meet the template of the beach fill project. The length of new (federal) work would be minimized, and consequently the frequency of ecological impacts would be reduced (i.e., not having two projects placing sediments on the same beaches of Atlantic Beach and/or Pine Knoll Shores). Incorporation of the dredge disposal operations into the storm damage reduction project design would also reduce the total amount of fill material necessary for dredging from offshore areas, which in turn would minimize the spatial scale of ecological impacts to benthic communities.

Lastly, known fishing grounds should be avoided as sediment sources to minimize impacts to fishery resources and the recreational and commercial fishing industry. These areas should be delineated via a thorough survey of recreational and commercial fishermen in the area. The North Carolina chart book can serve as a preliminary guide on advertised fishing grounds in the project area (GMCO 2001). Possible fishing grounds are indicated along the Cape Lookout shoals, the western side of Cape Lookout, at several artificial reefs and shipwrecks, at two locations along the Beaufort Inlet navigational channel and at the hardbottom areas south of Emerald Isle.

The first of the two fishing grounds near the navigational channel is advertised for king mackerel (*Scomberomorus cavalla*) and is found approximately half a mile landward of the seaward end of the navigational channel and overlapping the offshore dredged material site (in 14 to 40 feet of water). The second site is much larger, advertised for king mackerel and dolphin (*Coryphaena hippurus*), and starts just seaward of the last buoy marking the alignment of the navigational channel in 57 to 90 feet of water depth. Smaller areas within this large fishing grounds area include those known as “Northwest Places,” “Little 10 Fathom,” and “Big 10 Fathom.” Finally, the hardbottom areas offshore western Bogue Banks contain a fishing ground known as “45 Minute Rock” that is advertised for dolphin, sailfish (*Istiophorus platypterus*), king mackerel, and cobia (*Rachycentron canadus*). This area extends from roughly 56 to 67 feet of water depth.

For environmental impacts that are unavoidable and have been minimized to the extent feasible, mitigation measures may offset the adverse impacts. Impacts resulting from turbidity levels that exceed ambient levels, for instance, may be minimized by avoiding dredging muddy sediments, but not all of the turbidity can be avoided. As the beach fill dewaters (the slurry is 80-85% water and only 15-20% sediment), turbidity levels in the surf zone increase. If the fill material contains muddy or very fine-grained sediments, reworking of the fill by waves may elevate turbidity levels in the surf zone for extended periods of time (e.g., Appendix G). One measure that should minimize turbidity at the dredge site is to continuously monitor turbidity levels and stop dredging when the state saltwater quality standard of 25 NTUs is exceeded. If the background turbidity levels are less than 10 NTUs, though, water quality will be degraded while construction continues at the 25 NTU level. Furthermore, large dredge and fill projects that involve annual dredging and fill activities could increase a normally temporary impact to a persistent one.

If elevated turbidity levels are anticipated to be persistent, either as a result of reworked fill material or annual construction schedules, compensatory mitigation for water quality impacts should be implemented to offset the degradation to water quality. This can be done through the construction of oyster reefs, which are known for their water filtering capabilities. Although the oyster reefs would require placement within the estuaries of the project area, and are therefore not in the immediate vicinity of the impact area (the surf zone and the offshore dredge site), this difference can be compensated for by appropriate mitigation ratios for out-of-kind mitigation.

The many high value habitats within the project area call for no net loss of in-kind habitat value by the Service's Mitigation Policy. Avoiding dredging in Bogue Sound, Bogue Inlet and new areas of the nearshore and offshore marine areas should result in no net loss of habitat value. Avoiding construction of a bulldozed dune ridge or dike, and utilizing natural windblown processes and vegetation should result in no net loss to island interior habitats. Beaufort Inlet has a high to medium value, which calls for no net loss of habitat value while minimizing the loss of in-kind habitat value. Utilizing existing dredged material excavated from Beaufort Inlet and associated navigational channels should minimize any loss of in-kind habitat value. Recycling ecologically compatible materials from the nearshore and offshore disposal sites would also minimize the loss of new, undisturbed seabeds and potentially restore habitat value to these sites by returning them to a more natural bathymetry. The oceanfront beach proposed for fill placement has medium to low habitat value, and the mitigation goal for this resource category is to minimize loss of habitat value. Scheduling construction during periods of lower biological activity, using ecologically compatible fill material and breaking the project area into several shorter sections that receive fill on a rotating schedule should minimize the loss in habitat value for the oceanfront beaches. Additional protection measures for preserving habitat value include prohibiting or severely restricting beach scraping in between construction episodes and prohibiting beach driving during the sea turtle nesting season (beach driving is currently allowed starting in early September while turtle nests are still incubating).

Finally, although the scientific data on ecological impacts of dredge and fill projects has improved, biological monitoring continues to be a useful management tool. MMS (2001) recommends that an advisory team be convened to provide an adaptive management strategy as the biological and physical monitoring studies are finalized, initiated and completed. In this way modifications to study designs will ensure specific scientific questions are answered and spurious costs are avoided. If recovery is documented early in the project, then monitoring may be discontinued for the rest of the project's lifespan.

A threshold for recovery should be agreed to by an advisory team composed of the Corps, resource agencies, and the local sponsor prior to project construction. MMS (2001) recommends that recovery should be assumed when 95% of the mean values of species abundance, total biomass and estimated secondary production have returned to a particular site as compared to control sites. Depending on the longevity, size and frequency of impacts, other recovery thresholds may be appropriate. The Corps' recent New Jersey monitoring efforts utilized statistical techniques to determine when recovery was reached for abundance, biomass and taxa richness parameters (USACE 2001).

Monitoring should be conducted pre-construction, during construction, and post-construction until the pre-determined recovery threshold is reached. Maintenance events should reinitiate monitoring until the recovery threshold is again reached. At five year intervals the need for post-maintenance monitoring should be re-evaluated. Rates of recovery can be estimated by computing the rates at which means from fill and control areas converge (MMS 2001).

SECTION 10. CONSERVATION MEASURES AND RECOMMENDATIONS

The Service has previously summarized conservation measures that could be incorporated into an artificial beach and dune construction project in USFWS (1999), USFWS (2000a), USFWS (2000b), USFWS (2001) and USFWS (2002a). These reports are incorporated here by reference, and this section will focus on new findings not included in previous reports. The conservation measures are organized so that measures that would avoid adverse ecological impacts are presented first. Measures to minimize adverse impacts that are not avoidable are then described. Finally, compensatory mitigation options are summarized, utilizing the resource category determinations outlined in Section 6 and the Service's Mitigation Policy to suggest potential mitigation measures. Recommendations for these conservation measures are offered following the relevant conservation measures.

Measures to Avoid Ecological Impacts

There are several features of a beach fill design that potentially avoid adverse impacts to ecological resources. In general, the shorter the length of beach fill, the less the environmental impact. Avoiding placement of fill in areas close to inlets will limit indirect impacts of unwanted shoaling within navigation channels. The preliminary findings of the North Carolina Coastal Resources Commission (CRC) Science Panel on Coastal Hazards is that North Carolina inlets tend to influence oceanfront erosion and accretion for a mile or more on either side of the inlet. Beach fill placed in these areas is likely to be lost more quickly than in other areas and to alter the tidal currents and shoals in the adjacent inlet. While additional shoaling in some inlets may be beneficial to avian and fishery resources using the inlet, the subsequent increase in maintenance dredging and disposal may harm those resources more frequently and persistently. Therefore the Service recommends that:

1) The beach fill template should concentrate on areas more than approximately one mile from Bogue and Beaufort Inlets.

The inclusion of artificial dunes or levees in the beach fill design increases the ecological impact of a potential project. Bogue Banks is a sand-rich island with some of the highest and most massive dune fields in the state. Creation of new dunes or levees is not likely to appreciably increase the storm protection to structures. Bulldozing or beach scraping to build artificial dunes or levees adversely impacts the macroinvertebrate community of the oceanfront beach (Peterson et al. 2000; Peterson and Manning 2001). Avoiding extensive construction activities on the landward portion of the beach reduces the disturbance to ghost crab and sea turtle nesting habitat. Not constructing an artificial dune or levee would also avoid disturbance to the vegetative community present on the existing dunes, which provide foraging habitat and shelter to numerous terrestrial and avian fauna. Landscaping artificially constructed dunes or levees with nursery-raised dune grasses often establishes a monoculture with the aesthetic appearance of a cultivated field rather than the irregular and patchy distribution of natural pioneering plants. Therefore, we recommend:

2) The beach fill template should capitalize on natural processes and the existing dune system, and thereby avoid impacts to the natural dune community by incorporating sand fencing and diverse native vegetation in an irregular planting pattern. This would restore a foredune to the natural dune system of Bogue Banks instead of constructing an artificial dune.

In addition to measures that avoid indirect impacts to adjacent inlets and the dune system on Bogue Banks, the potential project could avoid impacts to offshore marine activities as well. There are currently 10 active and 33 inactive dredged material islands in the project area. Totaling ~387 acres, the dredged material islands represent an unknown quantity of sandy material that is likely to be ecologically compatible with the native oceanfront beaches of Bogue Banks. Over time as these dredged material islands become more vegetated and stabilized, their value to nesting shorebirds and colonies of waterbirds reduces as bare ground is lost and predators are introduced. These islands are also unnaturally sited within Bogue Sound, the White Oak River and Newport River estuaries. Selective removal of material from some of these dredged material islands could potentially restore estuarine fishery habitat and bare ground bird nesting areas. The capacity of the dredged material islands then increases for maintenance dredging disposal, and the islands could potentially be maintained in an early successional state that maximizes avian usage. Positive ecological benefits may result and offshore marine habitats would be avoided and undisturbed. Thus the Service recommends that:

3) The 43 dredged material islands within the project area should be considered as a sediment source, with associated positive ecological benefits of restoration incorporated into the economic cost and benefit analysis for this source.

Another avoidance measure would be to avoid dredging sediment from areas of high ecological value as defined in Section 5. Bogue Sound and Bogue Inlet are two such areas within the project area. Both of these areas are comparably undisturbed to similar habitats in North Carolina, and both generate significant commercial fish landings and recreational opportunities to the public. Direct impacts to fishery and avian resources can be avoided if no sediment dredging occurs within the natural habitats within Bogue Sound and Bogue Inlet. The integrity of the Bogue Inlet complex for migratory birds and larval fishery resources would be preserved. As a consequence, significant ecological impacts can be avoided if:

4) Bogue Inlet and natural areas within Bogue Sound are not used as a sediment source.

Bogue Banks supports one of few known commercial harvests of fishery resources on the oceanfront beach, a tradition with local residents. Heavy equipment on the beach and active pumping of beach fill during the annual harvest by these fishermen is likely to hamper or prevent their harvest and economic livelihood. The seasonality of this harvest indicates a period of high biological productivity in the surf zone of the project area, and a secondary benefit to avoiding conflicts between local fishermen and dredge equipment would be to avoid impacting the migratory fishery stocks present during that time. Therefore the Service recommends that the potential shore protection project:

5) Avoid construction during the fall season when local commercial fishermen are harvesting fish from the beach.

The Bogue Banks area also supports several fishing tournaments every year that attract national and international participants. These tournaments target King mackerel, Spanish mackerel, wahoo, tuna, dolphin, spotted seatrout, and blue marlin. Dredging equipment offshore would limit the area available for tournament participants to target. The operation of the dredging equipment would have an unknown acoustic effect on the sought-after migratory fish species and their prey. Local tournaments were scheduled during every month between June and November during 2001, usually for one week each. The high recreational value of these tournaments suggests that direct and indirect impacts to the tournaments and their sponsors could be avoided by not dredging offshore areas during those periods. Thus the Service recommends that:

6) Offshore marine dredging for beach fill sediment should not be conducted during periods of scheduled fish tournaments, typically the months of June to November.

Approximately seven miles of oceanfront beach in Atlantic Beach already receive dredged material from maintenance dredging of the Morehead City/State Port navigational channel on a periodic basis. As a result this oceanfront beach is already stabilized and the ecological community on its beaches disturbed every 6 to 8 years. Additional disturbances to this section of beach could be avoided if the Bogue Banks Shore Protection Study incorporates this existing dredged material disposal into the beach template for the island. The template for the dredge disposal could be modified to conform with the preferred template for the other sections of the island instead of placing additional fill in Atlantic Beach. If the dredged material pumpout on Atlantic Beach receives 50 cy/ft of beach, for example, but the shore protection project calls for 100 cy/ft of fill, then the dredged material project should be modified to a 100 cy/ft design template. In other words, development of consistent plans between the two projects would avoid ecological impacts resulting from a higher frequency of disturbance to beaches in Atlantic Beach (both projects alternately disturbing the same beach sections). Therefore, the Service recommends:

7) The dredged material disposal already occurring on the oceanfront beaches of Atlantic Beach should be modified to conform with the preferred design template instead of construction and maintenance of two separate projects in this area.

Finally, the potential beach fill project could avoid ecological impacts if it follows the purpose and intent of the Coastal Barrier Resources Act (CBRA). Several areas within the project area, most notably Hammocks Beach State Park, Fort Macon State Park and Shackleford Banks, have been designated as Otherwise Protected Areas (OPA) under the CBRA. While the only prohibition on federal expenditures within an OPA pertains to the National Flood Insurance Program (NFIP), the Service encourages federal activities within OPAs to preserve the integrity of the CBRA. Thus we recommend that:

8) Dredging of beach fill material should not occur within an OPA for placement outside of that OPA. Beach fill activities within an OPA should reduce federal expenditures, protect

fish and wildlife resources, and protect life and property.

Measures to Minimize Ecological Impacts

For those impacts that cannot be avoided, several options may minimize the scope and degree of the ecological impacts. For instance, fill material placed on the beach should match the native beach sediments in mineralogy, color, grain size distribution, grain shape or maturity, and compaction (or porosity). Macroinvertebrate infauna such as mole crabs and coquina clams are substrate sensitive, preferring certain grain size distributions and their corresponding geomorphic expressions (Alexander et al. 1993; Bowman and Dolan 1985; Donoghue 1999; Lindquist and Manning 2001; Peterson and Manning 2001). The potential impacts to sea turtle nests incubating in the new fill have been previously described (e.g., USFWS 2000a); successful incubation depends upon the moisture content, porosity, and mineralogical content of the beach fill material. Matching the fill sediments to the native sediments also preserves the aesthetic value and recreational experience of visitors to the new beach. Recovery times for fish and wildlife resources should be minimized if:

9) Sediment dredged for placement on the beach should be compatible with the native sediments of Bogue Banks.

The ~24 mile long oceanfront project area along Bogue Banks is the longest in North Carolina under consideration for an artificial beach fill project. The Dare County Beaches (Bodie Island Portion) Project divided its 14.2 mile length into three segments. Alternating construction amongst the three segments will minimize ecological impacts by limiting the length of beach affected in any given construction cycle. Assuming sections of beach influenced by adjacent inlets will be avoided, approximately 24 miles of Bogue Banks beaches could be directly impacted by fill placement and manipulation by heavy equipment. Division of this record length into four segments could minimize impacts if they are filled on a rotating schedule. Segments adjacent to each other should not be constructed consecutively, allowing for the quicker recovery of beach fauna because adjacent, undisturbed areas would be available for recruitment to the new fill. Therefore, the Service recommends that:

10) The 24 mile long Bogue Banks oceanfront shoreline could be divided into four sections that are constructed on a rotating schedule with adjacent sections constructed non-consecutively.

Impacts to sea turtles can be minimized by avoiding periods of highest use of the project area by these federally-protected fauna. If hopper dredges are used as part of the construction, they have the potential to take sea turtles when they are in the waters of the project area. Similarly, construction on the beach has the potential to take nesting sea turtles during warmer months when sea turtles are nesting, incubating and hatching on Bogue Banks beaches. Leatherback sea turtles (*Dermochelys coriacea*) have nested at Cape Lookout and Cape Hatteras National Seashore in recent years and during earlier months (e.g., April) than the more common loggerhead sea turtles (*Caretta caretta*). Consequently, we recommend that:

11) The construction schedule avoid using hopper dredges when waters exceed 11 degrees Celsius and avoid construction activities on the beach during the sea turtle nesting and hatching season (April 15 through November 15 annually).

Longer recurrence intervals between fill episodes (often referred to as "renourishment") minimize ecological impacts by allowing greater recovery times for fish and wildlife resources in the project area. The long-term resilience of coastal fauna to large-scale beach fill projects is unknown, but scientific findings so far suggest a one to three year interval is not sufficient in North Carolina (Donoghue 1999; Lindquist and Manning 2001). The comparably low erosion rates on Bogue Banks indicate that the maintenance interval will be longer than the standard 3 to 5 year cycle utilized for federal shore protection projects at Wrightsville Beach, Carolina Beach, and Kure Beach. The frequency of dredge disposal in Atlantic Beach is double that of these other Corps projects. Therefore the Service urges the Corps' project team to consider:

12) The maintenance construction, or renourishment interval, should be greater than three years.

Some portions of the offshore marine area have already been disturbed by dredging of navigational channels and disposal of dredge material. An offshore and a nearshore disposal area have been constructed off of Beaufort Inlet in the project area. While the ecological function and value of these offshore disposal areas is not readily known, they are artificial habitats not natural to the project area. The disposal sites are periodically disturbed by additional dredged material disposal and over time will have reduced capacity, necessitating the location of new disposal areas. The beach-quality sediment contained within these disposal sites was originally part of the estuarine and oceanfront beach system, and removal of the material from these littoral systems has had an unknown impact on the habitat value of the estuarine and oceanfront communities. Compared to undisturbed marine areas, dredging of these disposal areas to restore beach-quality sediments back to their original system is likely to minimize impacts to the offshore marine benthos. Thus the Service recommends that:

13) The ODMDS and nearshore disposal sites should be targeted for dredging before undisturbed marine areas, provided that the material is ecological compatible with the native sediments of Bogue Banks' beaches and free of toxicants.

Similar to Recommendation 10, the level of disturbance to the beach fauna may be further minimized by not directly placing fill within lands in conservation. Fort Macon State Park and the state park/regional access in Indian Beach could serve as ecological refuge(s) for beach fauna during fill construction. These relatively undisturbed areas (within the federal shore protection project) could then serve as recruitment populations for adjacent, filled areas. The fill template could be designed such that there are more abrupt transitions adjacent to these refuge areas instead of the usual tapered transitions. Natural redistribution of the fill material by wind and waves will generate accretion in the refuge areas, so they would be afforded some level of protection from storm-induced erosion. The natural accretion should minimize ecological impacts because the beach infauna presumably will be able to adapt to the natural influx of sediment easier than fill brought in via a dredge slurry and bulldozer. Consequently, the Service recommends that the Corps' project team evaluate the following:

14) Avoid filling conservation lands in the project area, allowing the natural drift of fill material into those areas instead of direct burial and manipulation by heavy equipment.

Faunal impacts to the dredge site may also be minimized by adjusting the construction methods and schedules. Shallower cuts are assumed to have less ecological impacts than deep cuts on the marine seafloor because alterations to the substrate, sedimentation, wave and current energy will be less. If the proposed dredge site is large, as the Dare County Beaches (Bodie Island) Project is at 7 square miles, limiting the excavation to small areas within the dredge site may reduce cumulative and long-term ecological impacts. Each dredging cycle could target a different portion of the dredge site, minimizing the frequency of disturbance and allowing longer benthic recovery times. Therefore the Service recommends that:

15) The construction methods and schedule should minimize the depth and spatial area dredged in any given dredging cycle to allow ecological recovery of the dredge site and offset long-term, cumulative impacts to the benthos.

Measures to Mitigate for Unavoidable Ecological Impacts

Specific compensatory mitigation measures will be recommended based upon specific project design features. In general, the Service would consider the following items as potential mitigative measures for a large-scale beach fill project. We encourage the Corps' project team to look for mitigation opportunities as the project design is formulated and evaluated.

16) If inlet shoal habitats are to be disturbed by sediment dredging, restoration of dredged material islands elsewhere within or adjacent to the inlet complex may mitigate diminished or lost functions and values to fish and wildlife resources and their dependent human uses.

17) If inlet or estuarine habitats are to be disturbed by sediment dredging, restoration of SAV areas in accordance with methods developed by the National Oceanic and Atmospheric Administration (NOAA) may mitigate diminished or lost aquatic spawning and rearing functions and values.

18) If an artificial dune or levee system is part of the preferred beach fill template, the purchase of property parcels or conservation easements along the oceanfront over time (i.e., the 50 year life of the project) if structures are destroyed by major storm events may mitigate for the long-term loss of the natural dune system by allowing the landward translation of the template over time.

19) If an artificial dune or levee system is part of the preferred beach fill template, the purchase of permanent, rolling construction and/or conservation easements between the mean high water line and the seaward edge of commercial and residential structures may

mitigate for impacts to the dry beach, dune toe and dune face habitats by allowing for the elimination of private or local beach scraping activities.

20) If elevated turbidity levels will result from the dredge and fill activities, one compensatory mitigation option is the creation of oyster reefs to offset impacts to degraded water quality and biological productivity.

21) If bird and sea turtle nesting habitat will be disturbed, restricting beach driving to non-nesting seasons (November 16 to March 1) and visible beach lighting during the nesting season (April 15 to November 15) may offset impacts to the quality of nesting habitat by enhancing the nesting environment.

Finally, long-term, scientifically rigorous, monitoring of evaluation species and their habitats may mitigate for the uncertainty associated with the long-term, potentially permanent, ecological impacts by allowing for future remedial measures based upon the findings of the monitoring. For example, documentation of the elimination of the local commercial beach fishery harvest would suggest future compensatory mitigation to the local fishermen. If the fill material is ecologically compatible with the native beach sediments of the project area, however, the ecological impacts may be inferred from similar projects elsewhere in the state. In that case, the monitoring should be designed specifically to answer remaining scientific questions. Some of these questions may include:

- Can benthic intertidal invertebrates be successfully collected ahead of the dredge pipeline and placed on new fill material behind the dredge pipeline? If so, does this result in quicker recovery of the beach ecosystem?
- Does the introduction of higher carbonate content within fill material significantly delay recovery of the beach by invertebrates, birds and fish as compared to beach fill without an increase in carbonate content?
- Do high carbonate contents within fill material significantly increase the permeability, porosity and resistence to wave and wind transport of the substrate? If so, how does that effect habitat quality for micro-, meio-, and macrofauna, and sea turtle nesting?
- What is the rate of bleaching of darker fill sediments on North Carolina beaches, and how deep does bleaching occur within the substrate? Does the bleaching alter the geochemistry of the substrate?
- Does the heavy mineral content of beach sediments adversely alter the geochemistry and gas diffusion rates of sediments at the depth of sea turtles nests?
- Do the native sands of North Carolina beaches (i.e., heavy mineral sands versus quartz sands) have significantly different heat capacities and therefore temperatures relevant to incubating sea turtles?
- Is the nutrient cycling within the beach sediments significant to filter-feeding benthos, and if so, how does a beach fill project alter the nutrient cycle?
- Is grain shape and/or roundness important to sandy beach invertebrates? Is the burrowing ability and/or burrow stability of ghost crabs significantly altered with different grain size distributions and compositions?
- Is there an aquatic seed bank of seabeach amaranth seeds that is responsible for

increased numbers of the plant following dredged material disposal activities?

- At what water depth and burial depth do coquina clams and mole crabs overwinter in offshore waters?
- Is the foraging efficiency (e.g., caloric intake per unit effort) of shorebirds decreased following a beach fill project, and if so, for how long?
- Does the short-term increase in turbidity within the surf zone and nearshore during and immediately following a dredged material disposal operation adversely impact fishery and benthic resources?

Due to the variety of unanswered scientific questions regarding the ecological impacts of beach fill projects, we recommend that:

22) If the beach fill material is ecologically compatible with the native beach sediments of the project area, the monitoring program should target remaining scientific questions and means to hasten ecological recovery of the project area.